A Multi-Channel Television Apparatus *

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A bar to the attainment of television images having a large amount of detail is set by the practical difficulty of generating and transmitting wide frequency bands. An alternative to a single wide frequency band is to divide it among several narrow bands, separately transmitted. A three-channel apparatus has been constructed in which prisms placed over the holes in a scanning disc direct the incident light into three photoelectric cells. The three sets of signals are transmitted over three channels to a triple electrode neon lamp placed behind a viewing disc also provided with prisms over its apertures so that each electrode is visible only through every third aperture. An image of 13,000 elements is thus produced. For the successful operation of the multi-channel system, it is imperative to have very accurate matching of the characteristics in the several channels.

IF, in a received television image, the individual image elements are, as they should be, of such a size as to be just indistinguishable, or unresolved, at a given observing distance, the number of image elements increases directly with the area of the image. The number of such indistinguishable elements in everyday scenes, in the news photograph, or in the frame of an ordinary motion picture is astonishingly large. An electrically transmitted photograph 5 inches by 7 inches in size, having 100 scanning strips per inch, has a field of view and a degree of definition of detail, which, experience shows, are adequate (although with little margin) for the majority of news event pictures. It is undoubtedly a picture of this sort that the television enthusiast has in the back of his mind when he predicts carrying the stage and the motion picture screen into the home over electrical communication channels. In this picture, the number of image elements is 350,000. At a repetition speed of 20 per second (24 per second has now become standard with sound films) this means the transmission of television signals at the rate of 7,000,000 per second,—a frequency band of 3½ million cycles on a single sideband basis. This may be compared to the 5,000 cycles in each sideband of the sound radio program, or it may be evaluated economically as the equivalent of a thousand telephone channels.

When we examine what has been achieved thus far in television, we find that the type of image successfully transmitted falls very far short of the finely detailed picture just considered. Probably the most satisfactory example of television thus far demonstrated is the

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72-line picture used in the two-way television-telephone installation of the American Telephone and Telegraph Company in New York.[1] Here the object to be transmitted is definitely restricted to the human face, which fills the whole field of view, and is adequately rendered by the 4,500 image elements used.

The gap between the 4,000 elements of this image and the 350,000 considered above is enormous, not only in figures, but in terms of technical possibility of bridging. Even if we are forced to content ourselves with relatively simple types of scenes for television transmission, still the fact must be squarely faced that a very much larger number of image elements must be transmitted than has thus far been found possible; and a far wider frequency band utilized than has ever been used in any communication problem. Now the situation is, simply stated, that *all parts of the television system are already having serious difficulty in handling the 4,500-element image.* Consequently, a *major problem in television progress is to develop means to extend the practical frequency range.*

It will be worth while to survey briefly the points in a television system where difficulty is now encountered when the attempt is made to increase the amount of image detail and the accompanying band of transmitted frequencies. Consider in turn the scanning discs at sending and receiving ends, the photoelectric cells, the amplifying systems, the transmission channels, the receiving lamps.

In the scanning disc at the sending end, which we shall assume arranged for direct scanning, increased detail means either loss of light or increase in the size of the disc. In either case, the factor of change involved is large. For instance, if the number of scanning holes is doubled in a disc of given size, providing four times the number of image elements, the holes must be spaced at half the angular distance apart, and twice the number of holes, imagined placed end to end, must be included in this half diameter scanning field. The holes will therefore be of one-quarter the diameter or 1/16 the area. The light falling on the photoelectric cell at any instant is the light transmitted by one hole; in this case, 1/16 the amount with the disc of half the number of holes. In general, the light transmitted by the disc to the cell decreases as the square of the number of image elements. If the disc is enlarged so as to hold the transmitted light unchanged, its diameter increases directly as the number of image elements. It is obvious that any considerable increase in the number of image elements—such as ten times—demands either enormously increased sensitiveness in our photo-responsive devices, or quite fabulous sizes of

[1] *Bell System Technical Journal*, July 1930, p. 448.

discs. Perhaps the most pertinent conclusion from this survey is that the disc, while quite the simplest means for scanning images of few elements, is entirely impractical when really large numbers of image elements are in question. As yet, however, no practical substitute for the disc of essentially different character has appeared.

Turning now to the photoelectric cell. The question of adequate sensitiveness to handle a large number of image elements is intimately connected with the method of scanning, as has just been brought out, so that no simple answer is possible. It is, however, probable that a very considerable increase in sensitiveness over anything now available must be anticipated, whatever scanning device is adopted. In the matter of frequency range there is definite information.[2] In cells depending on gas amplification (such as argon or neon) a characteristic behavior is a falling off of output with frequency, greater the higher the voltage used, which, becoming noticeable at about 20,000 cycles, may at 100,000 cycles be so considerable as to constitute a practical block to transmission. Vacuum cells are free from this failing, but are much less sensitive. Systematic experiment and development of photoelectric cells with particular reference to extending their range of frequency response is indicated as a necessary step in the attainment of a many-element image.

Taking up next the circuits associated with the photoelectric cell, we find, in general, that the higher frequencies progressively suffer from the electrical capacity of cells and associated wiring and amplifier tubes. This in turn calls for auxiliary equalizing circuits, with attendant problems of phase adjustment, and for increased amplification. Amplifiers capable of handling frequency bands extending from low frequencies up to 100,000 cycles or over offer serious problems.

Communication channels, either wire or radio, are characterized by increasing difficulty of transmission as the frequency band is widened. In radio, fading, different at different frequencies, and various forms of interference stand in the way of securing a wide frequency channel of uniform efficiency. In wire, progressive attenuation at higher frequencies, shift of phase, and cross-induction between circuits offer serious obstacles. Transformers and intermediate amplifiers or repeaters capable of handling the wide frequency bands here in question also present serious problems.

At the receiving end of the television system, conditions are similar to the sending end. The neon glow lamp, commonly used for reception, is already failing to follow the television signals well below 40,000 cycles, and, in the case of the 4,500-element image above

[2] Loc. cit., p. 456.

referred to, the neon must be assisted by a frequently renewed admixture of hydrogen, which again cannot be expected to increase the frequency range indefinitely. In the scanning disc, as at the sending end, increasing the number of image elements rapidly reduces the amount of light in the image. With a plate glow lamp of given brightness, the apparent brightness of the image is inversely as the number of image elements.

From this rapid survey, it is clear that at practically every stage in the television system, we encounter serious difficulties when a large increase in image elements is contemplated. It is not claimed that these difficulties are insuperable. One of the chief uses of a tabulation of difficulties is to aid in marshalling the attack upon them. But the existing situation is that if a many-element television image is called for today, it is not available, and *one of the chief obstacles is the difficulty of generating, transmitting, and recovering signals extending over wide frequency bands.*

One alternative, which prompted the experimental work to be described below, is the *use of multiple scanning, and multiple-channel transmission.* The general idea, which is obvious from the name given to the method, is to divide the image into groups of elements, the various groups to be simultaneously scanned, and to transmit the signals from the several groups through separate transmission channels. In place of apparatus to generate and transmit a frequency band of n cycles, we arrange m scanning processes each to provide frequency bands of n/m cycles width; n/m being chosen as within the limits set by the available practical elements of a television system. It will appear that the method which has been developed does provide an image of manyfold more image elements than heretofore, and may make easier the problem of transmission over practical transmission lines.

Description of a Three-Channel Apparatus

The multi-scanning apparatus which has been constructed and given experimental test uses scanning discs over whose holes are placed prisms of several different angles. At the sending end, the beams of light from successive holes are thereby diverted to different photoelectric cells. At the receiving end, the prisms similarly take beams of light from several lamps and divert them to a common direction. The mode of action of the prisms is illustrated in Fig. 1*a*, where a three-channel arrangement is shown, which is that actually used in the experimental apparatus. In the figure, the disc holes are shown disposed in a spiral, at such angular distances apart that three holes are always included in the frame f. Over the first hole of a

set of three is placed a prism P_1 which diverts the normally incident light upward; the second hole is left clear; the third is covered by a prism P_2 turned to divert the light downward. If we imagine the prisms removed and a single channel used instead of the three that are proposed, it is clear that the holes would have to be spaced three times as far apart so that no more than one would be included in the frame f at one time. The diameters of the holes, and the radial separation of the first and last in the spiral would be unchanged. Quite apart, therefore, from the smaller frequency bands which are sufficient to carry each of the three sets of signals, which is the principal objective sought, there is realized in this arrangement a reduced size of apparatus for the same size of disc holes.

Studying more closely the division of the light into three sets of beams, it is important to note that the signals transmitted by any one of the three sets of holes are continuous—as one hole of a given prism series passes out of the frame the next of the same series comes in. The signals generated in each photoelectric cell are accordingly exactly like those of a single-channel system.

Before describing the details of the apparatus, the general relationship between the number of image elements, band width, number of channels, and shape of picture may be developed. For this purpose, let the following symbols be used.

B = frequency band available in one channel, in cycles per second.
F = repetition frequency of images, per second.
C = number of communication channels.
n = total number of scanning holes.
a/b = ratio of tangential to radial dimensions of frame.
α = angular opening of frame.

We shall assume that the picture elements into which the frame is imagined divided are symmetrical in shape, i.e. either circles or squares. We then have that

the number of picture elements in the radial direction = number of holes $= n$;

the number of picture elements in the tangential direction $= (a/b)\cdot n$.

Now the number of signal cycles corresponding to this number of elements is $(1/2)\cdot(a/b)n$.

The number of cycles per second in one transit along the frame $= (1/2)\cdot(a/b)\cdot n\cdot F$;

over the whole picture it is $(1/2)\cdot(a/b)\cdot n\cdot F\cdot n = (1/2)(a/b)Fn^2$;

and the number of cycles per second for each channel $= (1/c) \cdot (1/2)(a/b)Fn^2 = B$.

The angular opening of the frame $\alpha = 360/n \times C$.

The number of picture elements $= n^2 \cdot (a/b)$.

These formulæ may be utilized upon assuming values for any of the variables, to fix the values of the other. In the present case, it was decided for reasons of simplicity to restrict the number of channels to 3.

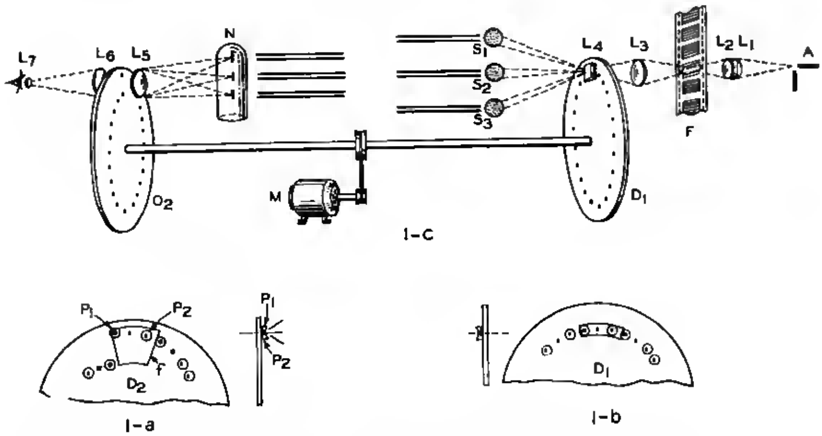

Fig. 1—Schematic of three-channel television apparatus. (*a*) Receiving end disc with spiral of holes provided with prisms. (*b*) Sending end disc with circle of holes provided with prisms. (*c*) General arrangement of apparatus.

The band width was chosen as that found feasible in the two-way television system, namely 40,000 cycles. The picture shape chosen was that of the sound motion picture, for which $a/b = 7/6$. The repetition frequency assumed was 18 per second, again following closely that of existing experimental synchronizing apparatus. Substituting these values in the formula rearranged to give n, we get for the number of holes,

$$n = \sqrt{\frac{2Bbc}{aF}} = 108$$

and for α,

$$\frac{360}{108} \times 3 = 10 \text{ degrees,}$$

for the number of picture elements,

$$n = (108)^2 \times \frac{7}{6} = 13{,}608.$$

In utilizing the prism disc principle at the sending end, direct

scanning, in which the object is imaged on the disc, was chosen, since beam scanning would introduce the problem of separating the light reflected from the object from the several spots simultaneously projected from the disc. Since the light going through the disc must be separated into several beams to be directed into separate photoelectric cells, the full aperture of the image forming lens must be divided by C, the number of channels, with a consequent proportional loss of light to each cell. (This loss counterbalances the decreased size of disc above noted.) It therefore becomes necessary to insure a very high illumination of the object. In the present case, it was decided to use motion picture film to provide the sending end image, since this can have a large amount of light concentrated through it by an appropriate lens system.

The use of motion picture film permitted a simplification of the transmitting disc, which is illustrated in Fig. 1*b*. This consists in arranging the scanning holes in a circle instead of a spiral, and producing the longitudinal scanning of the film by giving it a continuous uniform motion at right angles to the motion of the scanning holes. The continuous motion of the film also avoids the loss of transmission time that an intermittent motion demands for the shutter interval.

At the receiving end, a spiral of holes is used as shown in Fig. 1*a*. There again, because of the division of the light into three beams, the angle which can be subtended by the light source (neon lamp) is much restricted. In consequence, the neon lamp cathodes are of small area, and a lens system has been used to focus their images on the pupil of the observer's eye. Other methods of receiving, which promise to be less restricted as to position of observation, are possible, however, as discussed below.

With this survey of certain of the more important features of the system, we may proceed to a more detailed account of the apparatus as constructed. The general arrangement of parts is shown in Fig. 1*c* and in the photographs, Figs. 2, 3, 4 and 5 in all of which the symbols are uniform. Both sending and receiving discs were, for simplicity of operation, mounted on the same axis, driven by the motor M. This means that no question of synchronization entered. Synchronization is in fact a separate problem, having nothing to do with multi-channel operation and has been very completely solved in connection with other television projects.[1] If it should be decided to transmit the multichannel image to a distant point, the apparatus could be cut in two and each end, after separation to the desired distance, operated by synchronous motors controlled in approved fashion. Similarly, no long transmission lines were included.

Starting at the extreme right end of the schematic drawing Fig. 1*c*, we have an arc lamp A, a cylindrical lens L_1, a condensing lens L_2, the two lenses together concentrating a line of light on the film F. Between the film and the disc is a lens L_3 which images the film on the disc. Directly behind the disc D_1, with its circle of prism covered holes, is a second cylindrical lens L_4 which concentrates the transmitted

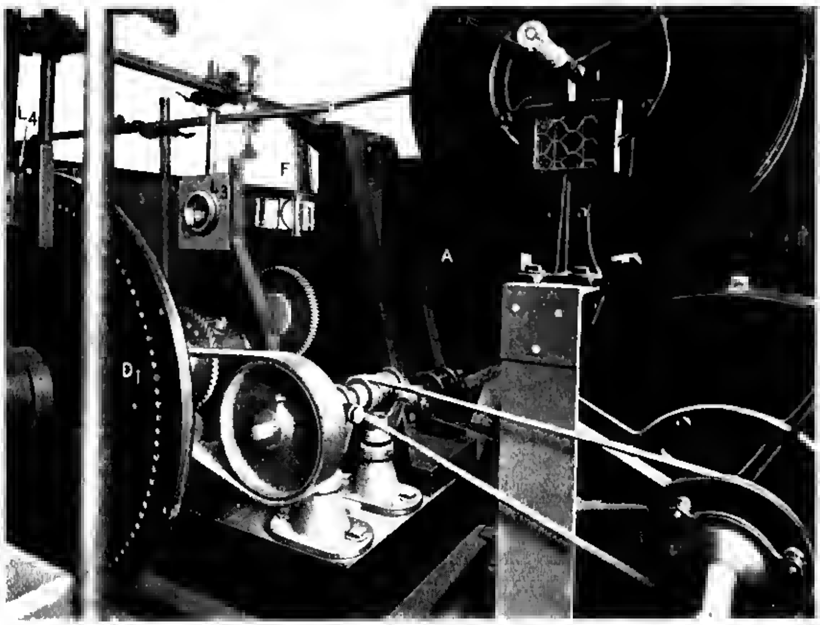

Fig. 2—Sending end of three-channel television apparatus, showing film driving arrangements.

light laterally, upon the three photoelectric cells S_1, S_2, S_3. By virtue of this lens arrangement, the light falls upon the cells in three small practically stationary spots. Additional apparatus not shown in the diagram but visible in the photographs are gears by means of which the film is driven from the disc axle through a differential, which permits the film to be framed up and down. The light beam is directed through the film at right angles to the axis of the discs by means of two prisms, whereby certain conveniences in driving and handling the film are attained.

The photoelectric cells are similar to ones previously described. The amplifier system was substantially identical with that used in the two-way television system, and need not be described again. Simi-

larly, the amplifiers at the receiving end were the actual set used in the three-color television apparatus previously described.[3]

At the receiving end, the three sets of signals were supplied to the three electrodes of a special neon lamp N, shown in Fig. 5, which is provided with a hydrogen valve to enable it to respond to the higher frequencies. Condensing lenses L_5 and L_6 image the three electrodes

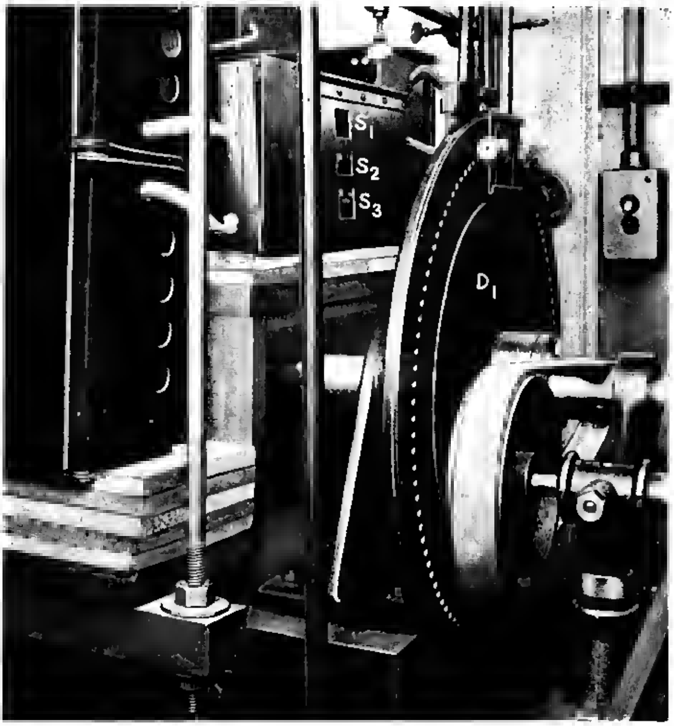

Fig. 3—Sending end of three-channel television apparatus, showing sending prism disc and photoelectric cells.

at the eye, where another lens L_7 is placed at the eye to focus the face of the disc D_2. By this system, nine electrode images are formed, of which three are superposed at the eye, and successive scanning holes are seen illuminated by each electrode in turn. This viewing arrangement, by which the image is visible to only a single eye, is adequate for an experimental investigation of the multi-channel method, but some other scheme would of course be needed if the method were developed into a practical form. Of several schemes, mention will be made here only

[3] *Journal of the Optical Society*, February, 1930, p. 11.

of the possible use of a triple grid of neon tubes, using a triple distributor of the type used in displaying images to a large audience in our initial work in 1927.[4]

Discussion of Results

The three-channel apparatus, when all parts are properly functioning, yields results strictly in agreement with the theory underlying its construction. The 13,500-element image, in resolving power and

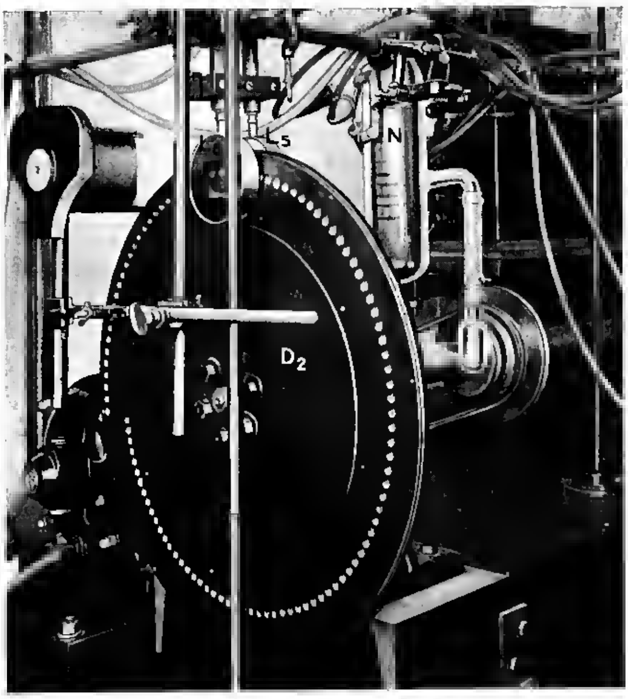

Fig. 4—Receiving end of three-channel television apparatus.

amount of detail handled, is a marked advance over the single-channel 4,500-element image. Even so, the experience of running through a collection of motion picture films of all types is disappointing, in that the number of subjects rendered adequately by even this number of image elements is small. "Close-ups" and scenes showing a great deal of action, are reproduced with considerable satisfaction, but scenes containing a number of full length figures, where the nature of the story is such that facial expressions should be watched, are very

[4] *Bell System Technical Journal*, October, 1927, pp. 551–652.

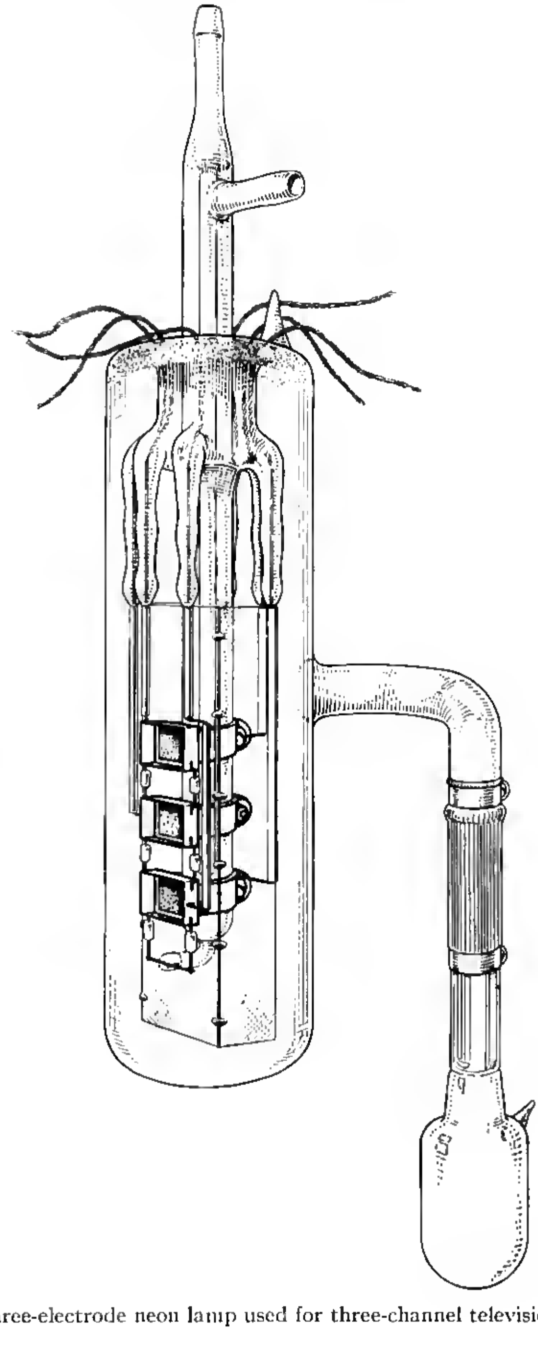

Fig. 5—Three-electrode neon lamp used for three-channel television reception.

far from satisfactory. On the whole, the general opinion expressed in an earlier paragraph is borne out, that an enormously greater number of elements is required for a television image for general news or entertainment purposes. This, however, was anticipated, and the real question is whether the results of this experiment indicate that the finer grain image is best attained by resort to multi-channel means.

This leads to a discussion of what has proved to be a serious practical difficulty with the multi-channel apparatus. This is *the problem of keeping the several channels properly related to each other in signal strength.* In the experimental apparatus, the direct current components (introduced at the receiving end) and the alternating current signals, are separately controlled, manually, by potentiometers. These have fine enough steps so that with care, with a non-changing image, a uniform picture may be obtained. If, however, for any reason the signals on one of the channels becomes too strong or too weak, the picture exhibits at once a strongly lined appearance. The eye is quite sensitive to irregularity of this sort, and the transition from a smooth grainless image to one showing a periodicity of 1/3 the number of constituent lines largely offsets the higher resolving power afforded by the actual number of scanning lines used. A characteristic practical defect of the system as set up is that any marked change in the general character of the signal, such as is produced by a shift from close-up to a wide angle view may throw out the existing signal balance sufficiently to show objectionable grain in the picture.

Differences of this sort in the three signals are of course caused in general by differences in the characteristics of the three circuits. Such differences can arise from overloading of amplifier tubes, whereby one or more may be working on a non-linear portion; by rectifying action of different amounts in the tubes immediately associated with the neon lamps, or in the neon lamp electrodes themselves. A remedy is the careful design and test of all parts of the system to insure the greatest possible uniformity of performance. When this is carefully done, the behavior of the three signals is reasonably satisfactory.

Conclusion

We are, as a consequence of this work, in a position to make a general comparison of the two chief theoretical means for achieving a television image of extreme fineness of grain, which are (1) extension of the frequency band, and (2) the use of several relatively narrow frequency bands. Both, because of the diminished amount of light which finer image structure entails, demand enhanced sensitiveness of the photo-sensitive elements at the sending end, and increased efficiency

fo the light sources at the receiving end. The multi-channel scheme described has some advantage in compactness over the equivalent single-channel apparatus, but since it is restricted to narrow angles of illumination of the discs the overall efficiency of light utilization is not essentially different. Comparing now the demands made upon the electrical systems the differences between the two methods are clear cut. Method (1) demands an extension of the frequency range of all parts of the apparatus, the attainment of which depends upon physical properties and technical devices whose mastery lies in the indefinite future. Method (2) demands a multiplication of apparatus parts, and careful design and construction of these parts so as to insure accurately similar operation of a considerable number of electrical circuits and terminal elements. The attainment of the necessary uniformity of performance of the several electrical circuits and terminal elements, while involving no fundamental problems, must present increasing difficulty with the number of channels used.